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AN EQUATION FOR PREDICTING THE RESIDUAL STATIC STRENGTH OF STIFFENED PANELS

By

I. E. Figge, Sr.

April 1970

U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

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AN EQUATION FOR PREDICTING THE RESIDUAL STATIC STRENGTH OF STIFFENED PANELS

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ABSTRACT

An equation has been developed to predict the residual static strength of stiffened panels. All parameters in the equation can be evaluated from tests on simple unstiffened specimens. The stiffened panel is treated as a composite material, with the sheet material representing the matrix and the stiffeners representing the fibers. The residual static strength of the cracked sheet, calculated using notch strength analysis, and the proportional limit of the stiffeners are used in the law-of-mixtures equation to calculate the residual static strength of the stiffened panels.

Excellent predictions of the residual static strength of stiffened panels have been obtained and are presented for a wide variety of panel configurations, type fasteners, and crack geometry.

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a	one-half crack length, in.
$A_{net(sheet)}$	net section area of sheet (panel width minus crack length, times thickness), in.^{2}
$A_{net(stiff)}$	net section area of remaining stiffeners, in.^{2}
A_{st}	area of stiffener, in.^{2}
C_M	material constant obtained from experimental data on unstiffened panels (Reference 5), in.$^{-\frac{1}{2}}$
D	rivet diameter, in.
F	stiffener failed prior to testing
K_u	static notch strength factor
P	rivet pitch, in.
$PL_{(stiff)}$	proportional limit of stiffener, ksi
S	stiffener spacing, in.
S_{net}	net section stress based on total area (skin plus stiffener), ksi
$S_{net(cal)}$	calculated net section stress based on total area (skin plus stiffener), ksi
$S_{net(exp)}$	experimental net section stress based on total area (skin plus stiffener), ksi
t	sheet thickness, in.
W	specimen width, in.
ρ'	material constant (Neuber constant), in.
$\sigma_{u(sheet)}$	ultimate tensile strength of sheet, ksi

$\sigma_{u(stiff)}$ ultimate tensile strength of stiffener, ksi

INTRODUCTION

Current fail-safe design philosophy dictates the need for a practical method to predict the residual static strength of damaged or cracked structures. Several methods exist for predicting the residual strength behavior of unstiffened panels; for example, fracture mechanics, notch strength analysis, and effective width approach. If these methods are properly applied and their inherent limitations are recognized, acceptable engineering predictions can be made. Prediction methods for stiffened panels are somewhat more limited in their capability of making satisfactory predictions for a wide variety of configurations. Often the designer is forced to rely on experimental data obtained from stiffened panels that are similar, if not identical, to those he will ultimately use. Obviously, this approach is both time-consuming and costly.

Based on the need for a simple method to predict the residual strength of stiffened panels, it was the purpose of this study to develop a method which required only basic material properties and data from unstiffened panels to make the predictions.

BACKGROUND

The need for an improved method to predict the residual static strength of stiffened panels became apparent when some unpublished NASA data* on 30-inch-wide 2024-T3 and 7075-T6 aluminum panels with riveted aluminum stiffeners were being studied. In the NASA data, the ratio of stiffener area to skin area varied from 19 to 56 percent and the percentage of total area that failed (prior to testing) ranged from 12 percent to 66 percent. Interestingly, the test results indicated that the ratio of stiffener area to skin area had no apparent effect on the residual strength behavior, as shown in Figures 1 and 2. Since configuration had no apparent effect on the behavior, a single curve could be faired through all the data for a given material. Although the scatter was quite large, the curves indicate the trend of the data. Comparison of these faired curves indicates that the curve for the 7075-T6 material falls above the curve for the 2024-T3 material. Typically, for unstiffened panels,[2] the order of the curves is reversed; that is, the curve for the 2024 material falls above the curve for the 7075 material (see Figure 3).

For the curves presented in Figures 1 and 2, it became obvious that the methods commonly used to predict the residual static strength of stiffened panels (for example, Greif and Sanders[3] and Romualdi et al[4]) would not result in suitable predictions since their approach is to adjust the unstiffened data by a factor which is some function of the specimen geometry (stiffener spacing, area, etc.) and the ratio of sheet to stiffener material moduli. In the NASA data, the stiffener and sheet material have identical moduli; therefore, the commonly used methods would result in adjustment of both curves in Figure 3 by the same factor. Thus, using these approaches would result in predicted curves ordered as shown in Figure 3, not as the actual results as shown in Figures 1 and 2.

*Unpublished data obtained from additional testing on panels described in Reference 1.

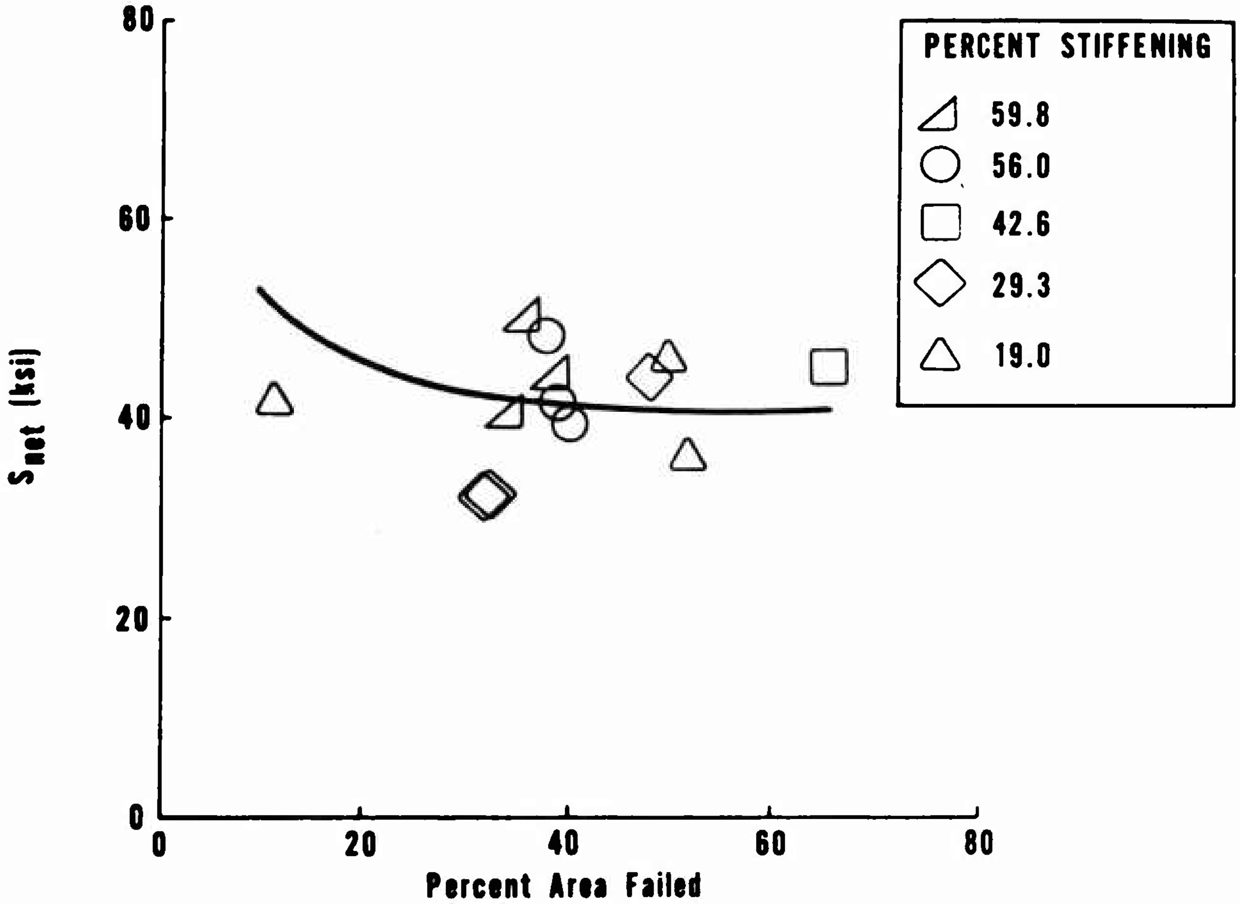


Figure 1. Residual Static Strength of Stiffened 7075-T6 Aluminum Panels.

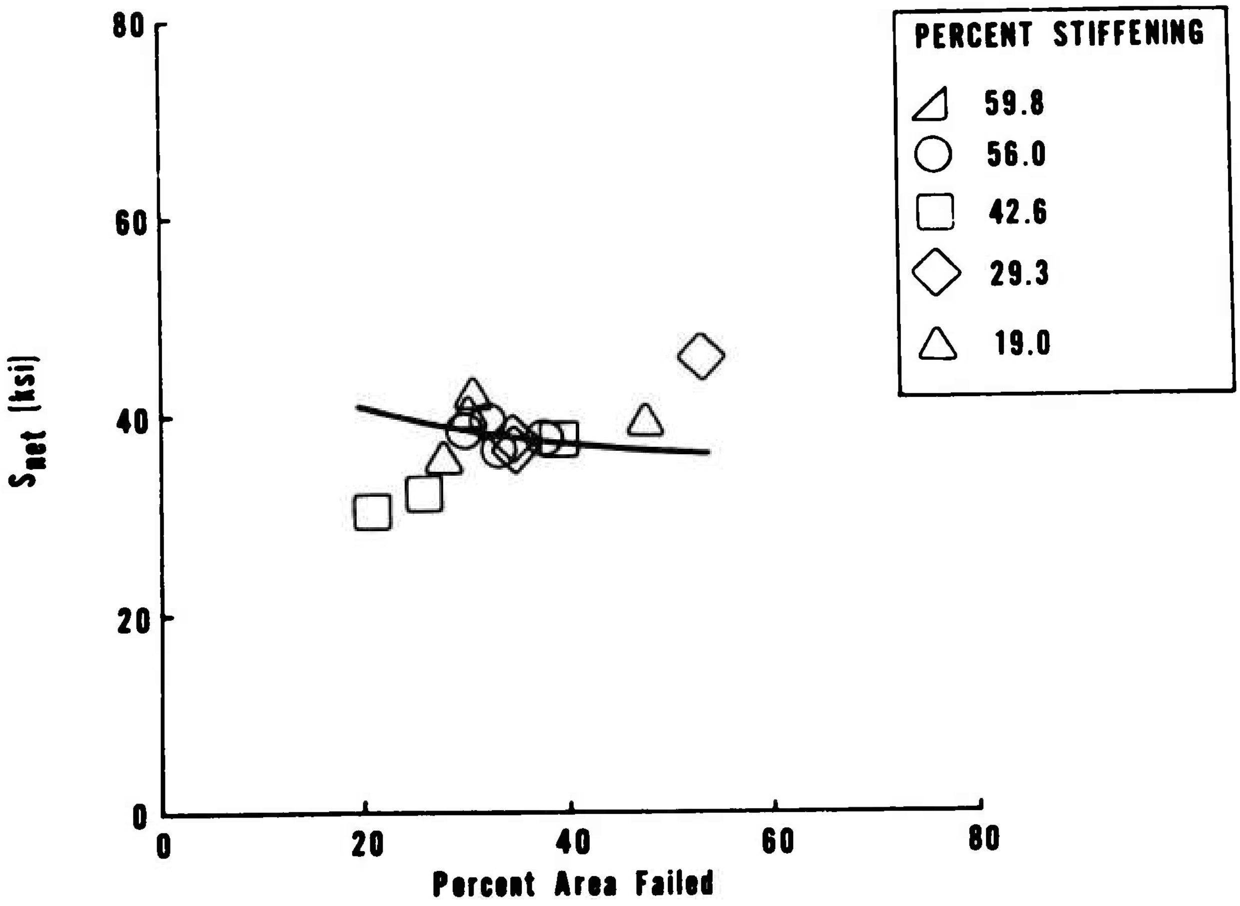


Figure 2. Residual Static Strength of Stiffened 2024-T3 Aluminum Panels.

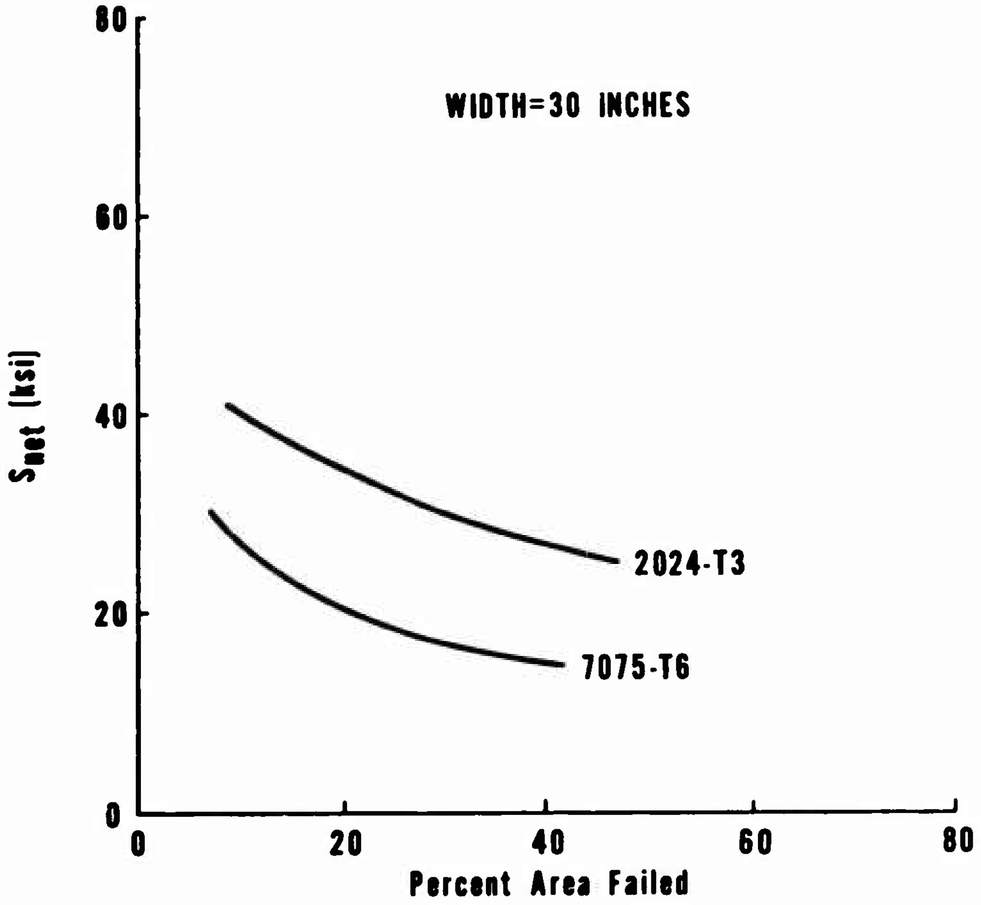


Figure 3. Typical Residual Static Strength Behavior of Unstiffened 2024 and 7075 Aluminum Panels.

METHOD

The approach presented herein is to treat the panel as a composite material, with the sheet material representing the matrix and the stiffeners representing the fibers. The residual static strength of the crack sheet, calculated using notch strength analysis,[2] and the proportional limit of the stiffeners are used in the law-of-mixtures equation, which has been shown to be applicable in predicting the strength of metal-metal composites (see, for example, Reference 5). It is assumed that the proportional limit of the stiffener is the limiting stress at which the stringer is effective in retarding the failure process.

The equation for predicting the residual static strength (S_{net}) of stiffened panels is as follows:

$$S_{net} = \begin{matrix}\text{Residual Static Strength} \\ \text{of Sheet Material}\end{matrix} \left(\frac{\text{Net Sheet Area}}{\text{Total Area}}\right)$$

$$+ \begin{matrix}\text{Proportional Limit} \\ \text{of Stiffeners}\end{matrix} \left(\frac{\text{Net Stiffener Area}}{\text{Total Area}}\right)$$

Then,

$$S_{net} = \frac{\sigma_{u(sheet)} A_{net(sheet)}}{K_u \left[A_{net(sheet)} + A_{net(stiff)}\right]}$$

$$+ \frac{PL_{(stiff)} A_{net(stiff)}}{\left[A_{net(sheet)} + A_{net(stiff)}\right]} \qquad (1)$$

where $\sigma_{u(sheet)}$ = ultimate strength of sheet material, ksi

$PL_{(stiff)}$ = proportional limit of stiffener, ksi

$A_{net(sheet)}$ = net section area of sheet (panel width minus crack length, times thickness), in.^{2}

$A_{net(stiff)}$ = net section area of remaining stiffeners, in.^{2}

K_u = static notch strength factor

The static notch strength factor is calculated by using the following equation:

$$K_u = 1 + C_M \sqrt{a} \sqrt{\frac{1 - 2a/W}{1 + 2a/W}} \tag{2}$$

where C_M = material constant obtained from experimental data on unstiffened panels, in.$^{-\frac{1}{2}}$

a = one-half crack length, in.

W = specimen width, in.

Equation (1) requires only knowledge of basic material properties, that is, ultimate tensile strength and proportional limit, and sufficient residual static strength data on unstiffened panels to obtain the material constant, C_M (see Reference 6). For aluminum and some titanium alloys, the value of K_u can be calculated by using the curves presented in References 2 and 7 respectively.

AGREEMENT BETWEEN PREDICTION AND EXPERIMENTAL DATA

A literature survey was conducted to obtain test data covering a wide range of materials and specimen configurations. Although the search was extensive, only a limited amount of experimental data was available (References 8 through 11).

To demonstrate the overall applicability of the proposed method, no attempt was made to adjust the value of C_M for each specific set of data; rather, typical values of C_M were used in the calculations. Also, since the proportional limits were not quoted in the referenced reports, typical values were used. A summary of the values that were used in the calculations is presented in Table I.

TABLE I. CONSTANTS USED TO CALCULATE RESIDUAL STATIC STRENGTH OF STIFFENED PANELS

Material	C_M (in.$^{-\frac{1}{2}}$)	Proportional Limit (ksi)
2024-T3 Bare and Clad	0.65	45
7075-T6 Bare and Clad	1.90	55
PH14-8 (SRH 1050)	0.70	189
Ti8Al-1Mo-1V	0.60	116

In the case of Reference 8, notched panels rather than fatigue cracked panels were tested. Calculation of K_u for notched panels requires the approach described in Reference 2. For the data in this report, the values of $\sqrt{\rho'}$ (material constant required to calculate K_u for notched specimens) were the same as those used in Reference 8 (see Table II).

TABLE II. RESIDUAL STATIC STRENGTH OF STIFFENED PANELS

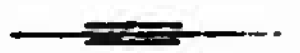
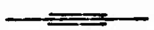
Specimen Cross Section	Sheet Thick. (in.)	Stiffener Size (in.)	Area of Each Stiffener (in.^{2})	No. of Stiffeners Failed	Stiffener Spacing (in.)	Rivet Pitch (in.)	Rivet Dia (in.)	Total Crack Length (in.)	Total Area Failed (pc.)	$S_{net(exp)}$ (ksi)	$S_{net(cal)}$ (ksi)	$\frac{S_{net(exp)}}{S_{net(cal)}}$
	Material: 7075-T6 Clad $PL_{(stiff)}$ = 55 ksi (est)				$\sigma_{u(sheet)}$ = 76 ksi $\sigma_{u(stiff)}$ = 81 ksi					C_M = 1.90 in.$^{-\frac{1}{2}}$ W = 30 in.		
	0.051	1 x 1 x 1/8	0.234^a	2	(e)	0.5	5/32	17.75	40.6	38.7	44.2	0.87
	0.051	1 x 1 x 1/8	0.234^a	2	(e)			16.63	38.9	41.5	43.5	0.95
	0.051	1 x 1 x 3/32	0.234^a	2	(e)			16.50	38.7	47.8	43.4	1.10
	0.064	1 x 1 x 3/32	0.178^b	4	(e)			22.50	66.0	43.2	41.4	1.04
	0.081	1 x 1 x 1/16	0.122^c	2	(e)			10.38	32.4	31.2	30.3	1.02
	0.081	1 x 1 x 1/16	0.122^c	2	(e)			17.00	48.4	42.8	34.1	1.25
	0.102	3/4 x 3/4 x 1/16	0.089^d	2	(e)			16.50	50.5	44.3	29.1	1.52
	0.102	3/4 x 3/4 x 1/16	0.089^d	0	(e)			4.63	12.9	40.8	28.9	1.41
	0.102	3/4 x 3/4 x 1/16	0.089^d	2	(e)			17.13	52.3	34.9	29.5	1.18
	0.051	1 x 1 x 1/8	0.234^a	2	(e)			11.63	33.4	35.6	40.7	0.87
	0.051	1 x 1 x 1/8	0.234^a	2	(e)			15.01	38.9	39.4	42.4	0.92
	0.051	1 x 1 x 1/8	0.234^a	2	(e)			13.38	36.3	43.9	41.5	1.05
	Material: 7075-T6 $PL_{(stiff)}$ = 55 ksi (est)				$\sigma_{u(sheet)}$ = 82.4 ksi $\sigma_{u(stiff)}$ = 82.4 ksi					$\sqrt{\rho'}$ = 0.144 in. W = 12 in.		
	0.064	3.75 x 0.064	0.240	0	-	9/16^f	3/16	1.50^h	9.6	61.3	53.0	1.33
	0.064	2.56 x 0.250	0.640		-	9/16^g	3/16	4.00^h	12.5	55.1	52.6	1.05
	0.064	0.50 x 0.064	0.032		-	3/8	1/8	0.50^h	4.0	66.5	58.5	1.13
	0.064	0.75 x 0.064	0.048		-	3/8	1/8	1.50^h	11.1	56.0	51.1	1.05
	0.064	1 x 1 x 3/32	0.178		-	9/16	3/16	2.78^h	18.8	42.7	47.3	0.90

Table II - Continued

Specimen Cross Section	Sheet Thick. (in.)	Stiffener Size (in.)	Area of Each Stiffener ($in.^2$)	No. of Stiffeners Failed	Stiffener Spacing (in.)	Rivet Pitch (in.)	Rivet Dia (in.)	Total Crack Length (in.)	Total Area Failed (pct)	$S_{net(exp)}$ (ksi)	$S_{net(cal)}$ (ksi)	$\frac{S_{net(exp)}}{S_{net(cal)}}$
	Material: 7075-T6 $PL_{(stiff)}$ = 55 ksi (est)				$\sigma_{u(sheet)}$ = 82.4 ksi $\sigma_{u(stiff)}$ = 82.4 ksi					$\sqrt{\rho'}$ = 0.144 in. W = 12 in.		
	0.064	2.78 x 0.064	0.178	0	-	9/16	3/16	2.78[h]	18.8	48.5	47.3	1.02
	0.064	2.78 x 0.064	0.178		-	2-3/4	3/16	2.78[h]	18.8	40.3	47.3	0.85
	0.064	2.78 x 0.064	0.178		-	5-1/2	3/16	2.78[h]	18.8	37.2	47.3	0.79
	0.064	3.0 x 0.064	0.192		-	9/16	3/16	6.00[h]	33.3	41.5	50.1	0.83
	0.064	3.0 x 0.064	0.192		-	9/16	3/16	6.00[h]	33.3	44.5	50.1	0.89
	0.064	0.51 x 0.025	0.0128		-	3/8	1/8	1.00[h]	8.2	55.8	54.1	1.03
	0.064	0.50 x 0.064	0.032		-	3/8	1/8	2.50[h]	20.0	42.9	47.3	0.90
	0.064	0.80 x 0.064	0.0512		-	3/8	1/8	4.00[h]	31.3	41.1	46.3	0.89
	0.064	1.2 x 0.064	0.0768		-	9/16	3/16	6.00[h]	45.5	40.5	47.0	0.86
	Material: 2024-T3 Clad $PL_{(stiff)}$ = 45 ksi (est)				$\sigma_{u(sheet)}$ = 65 ksi $\sigma_{u(stiff)}$ = 57 ksi					C_M = 0.65 $in.^{-\frac{1}{2}}$ W = 30 in.		
	0.051	1 x 1 x 1/8	0.234[a]	2	(e)	0.5	5/32	10.94	30.0	38.3	39.7	0.96
	0.051	1 x 1 x 1/8	0.234[a]		(e)			12.38	32.5	38.8	39.9	0.97
	0.051	1 x 1 x 1/8	0.234[a]		(e)			16.13	38.2	36.5	40.8	0.89
	0.051	1 x 1 x 1/8	0.234[a]		(e)			13.06	33.5	35.7	40.0	0.89
	0.064	1 x 1 x 3/32	0.178[b]		(e)			10.25	31.2	34.3	37.9	0.90
	0.064	1 x 1 x 3/32	0.178[b]		(e)			14.50	38.9	36.4	38.6	0.94
	0.064	1 x 1 x 3/32	0.178[b]		(e)			11.50	34.7	36.2	38.0	0.95
	0.064	1 x 1 x 3/32	0.178[b]		(e)			7.50	25.7	31.3	38.0	0.82
	0.081	1 x 1 x 1/16	0.122[c]		(e)			10.31	32.[illegible]	35.5	36.1	0.98

Table II - Continued

Specimen Cross Section	Sheet Thick. (in.)	Stiffener Size (in.)	Area of Each Stiffener (in.²)	No. of Stiffeners Failed	Stiffener Spacing (in.)	Rivet Pitch (in.)	Rivet Dia (in.)	Total Crack Length (in.)	Total Area Failed (pct)	$S_{net(exp)}$ (ksi)	$S_{net(cal)}$ (ksi)	$\frac{S_{net(exp)}}{S_{net(cal)}}$
	Material: 2024-T3 Clad $PL_{(stiff)}$ = 45 ksi (est)				$\sigma_{u(sheet)}$ = 65 ksi $\sigma_{u(stiff)}$ = 57 ksi						C_M = 0.65 in.$^{-\frac{1}{2}}$ W = 30 in.	
	0.081	1 x 1 x 1/16	0.122[c]	2	(e)	0.5	5/32	19.00	53.2	44.7	38.6	1.15
	0.081	1 x 1 x 1/16	0.122[c]		(e)			11.47	35.0	35.2	36.2	0.97
	0.102	3/4 x 3/4 x 1/16	0.089[d]		(e)			8.88	29.4	33.4	34.8	0.96
	0.102	3/4 x 3/4 x 1/16	0.089[d]		(e)			15.50	47.8	38.0	35.5	1.06
	0.102	3/4 x 3/4 x 1/16	0.089[d]		(e)			8.50	28.4	34.6	34.9	0.99
	0.102	3/4 x 3/4 x 1/16	0.089[d]		(e)			9.63	31.5	40.7	34.7	1.17
	0.102	3/4 x 3/4 x 1/16	0.089[d]		(e)			9.40	30.9	37.9	34.7	1.09
	Material: 2024-T3 Alclad $PL_{(stiff)}$ = 45 ksi (est)				$\sigma_{u(sheet)}$ = 66 ksi $\sigma_{u(stiff)}$ = 66 ksi						C_M = 0.65 in.$^{-\frac{1}{2}}$ W = 57 in.	
	0.033	-	0.095	0	19	-	-	14.4	21.9	23.3	31.8	0.75
	0.033	-	0.095	0	19	-	-	14.2	21.6	23.3	31.8	0.75
	0.031	-	0.095	0	19	-	-	14.33	21.0	26.4	32.6	0.83
	0.032	-	0.183	1	19	-	-	13.91	26.5	28.9	32.8	0.91
	0.032	-	0.143[i]	1[k]	19	-	-	14.58	27.4	30.5	32.7	0.96
	0.030	-	0.081	1	9.5	-	-	14.32	24.2	32.1	32.6	1.01
	0.032	-	0.134[j]	1[k]	9.5	-	-	15.88	27.5	37.3	34.8	1.12

Table II - Continued

Specimen Cross Section	Sheet Thick. (in.)	Stiffener Size (in.)	Area of Each Stiffener (in.^{2})	No. of Stiffeners Failed	Stiffener Spacing (in.)	Rivet Pitch (in.)	Rivet Dia (in.)	Total Crack Length (in.)	Total Area Failed (pct)	$S_{net(exp)}$ (ksi)	$S_{net(cal)}$ (ksi)	$\frac{S_{net(exp)}}{S_{net(cal)}}$
	Material: 2024-T3 $PL_{(stiff)}$ = 45 ksi (est)				$\sigma_{u(sheet)}$ = 72.2 ksi $\sigma_{u(stiff)}$ = 72.2 ksi					$\sqrt{\rho'}$ = 0.150 in. W = 12 in.		
	0.064	0.50 x 0.064	0.032	0	-	3/8	1/8	0.50^h	4.0	51.8	52.9	0.98
	0.064	0.75 x 0.064	0.048		-	3/8	1/8	1.50^h	10.0	55.3	50.3	1.10
	0.064	1 x 1 x 3/32	0.178		-	9/16	3/16	2.78^h	18.8	50.4	48.7	1.03
	0.064	2.78 x 0.064	0.178		-	9/16	3/16	2.78^h	18.8	51.2	48.7	1.05
	0.064	2.0 x 0.064	0.128		-	9/16	3/16	4.00^h	25.0	50.4	48.2	1.04
	0.064	3.0 x 0.064	0.192		-	9/16	3/16	6.00^h	33.3	49.2	47.3	1.04
	0.064	0.51 x 0.025	0.0128		-	3/8	1/8	1.00^h	8.2	52.6	52.6	1.00
	0.064	0.50 x 0.064	0.032		-	3/8	1/8	2.50^h	20.0	50.4	50.0	1.01
	0.064	0.80 x 0.064	0.0512		-	3/8	1/8	4.00^h	31.3	47.3	49.2	0.96
	0.064	1.20 x 0.064	0.0768		-	9/16	3/16	6.00^h	45.5	45.6	48.8	0.93

Table II - Continued

Specimen Cross Section	Sheet Thick. (in.)	Stiffener Size (in.)	Area of Each Stiffener ($in.^2$)	No. of Stiffeners Failed	Stiffener Spacing (in.)	Rivet Pitch (in.)	Rivet Dia (in.)	Total Crack Length (in.)	Total Area Failed (pct)	$S_{net(exp)}$ (ksi)	$S_{net(cal)}$ (ksi)	$\frac{S_{net(exp)}}{S_{net(cal)}}$
	Material: 2024-T3 Alclad Stiffeners: 7075-T6 Alclad $PL_{(stiff)}$ = 55 ksi (est)				$\sigma_{u(sheet)}$ = 62 ksi $\sigma_{u(stiff)}$ = 74 ksi						$C_M = 0.65\ in.^{-\frac{1}{2}}$ W = 35 in.; last two cross sections, W = 48 in.	
	0.040	-	0.121	0	9	-	-	5.10	10.8	40.8	39.1	1.04
	0.039	-	0.061		9	-	-	5.10	12.4	38.9	36.6	1.06
	0.040	-	0.121		12	-	-	5.11	10.8	36.8	39.1	0.94
	0.039	-	0.061		12	-	-	5.10	12.4	35.2	36.5	0.96
	0.040	-	0.186		9	-	-	5.01	9.3	43.0	41.3	1.04
	0.039	-	0.188		12	-	-	5.03	9.3	39.0	41.5	0.94
	0.040	-	0.039		6	-	-	5.11	12.5	39.5	36.3	1.08
	0.040	-	0.119		6	-	-	5.20	9.8	46.8	41.0	1.14
	0.040	-	0.093		15	-	-	5.18	9.0	34.6	36.1	0.95
	0.041	-	0.298		15	-	-	5.04	6.5	41.7	41.4	1.00

Table II - Continued

Specimen Cross Section	Sheet Thick. (in.)	Stiffener Size (in.)	Area of Each Stiffener (in.²)	No. of Stiffeners Failed	Stiffener Spacing (in.)	Rivet Pitch (in.)	Rivet Dia (in.)	Total Crack Length (in.)	Total Area Failed (pct)	$S_{net(exp)}$ (ksi)	$S_{net(cal)}$ (ksi)	$\frac{S_{net(exp)}}{S_{net(cal)}}$	$\sigma_{u(sheet)}$ (ksi)	$\sigma_{u(stiff)}$ (ksi)
	Material: Ti 8-1-1 Duplex Annealed $PL_{(stiff)}$ = 116 ksi										C_M = 0.60 in.$^{-\frac{1}{2}}$ W = 12 in.			
	0.050	1 x 0.025	0.025	0	4	0.50[l]	1/8	2.75	21.1	103.4	95.8	1.07	145.8	153.0
	0.050	1 x 0.050	0.050			1.00[l]	5/32		19.6	98.0	94.7	1.03	140.2	141.5
	0.050	1 x 0.100	0.100			1.00[l]	5/32		17.2	98.9	98.7	1.00	142.1	141.5
	0.050	1 x 0.025	0.025			0.50[l]	1/8		21.1	104.0	92.1	1.12	139.4	153.5
	0.050	1 x 0.050	0.050			1.00[l]	5/32		19.6	98.7	95.3	1.03	141.5	141.5
	0.050	1 x 0.100	0.100			1.00[l]	5/32		17.2	100.4	96.4	1.04	137.0	141.5
	0.050	1 x 0.025	0.025			Seam[m]	-		21.1	104.0	93.9	1.10	142.5	153.0
	0.050	1 x 0.025	0.025			Seam[m]	-		21.1	102.4	95.4	1.07	145.0	153.0
	0.050	1 x 0.025	0.025			0.50[n]	-		21.1	94.8	94.8	1.00	144.1	153.0
	0.050	1 x 0.025	0.025			0.50[m]	-		21.1	102.0	94.5	1.07	143.6	153.0
	0.050	1 x 0.050	0.050			Seam[m]	-		19.6	108.4	93.8	1.15	138.6	141.5
	0.050	1 x 0.050	0.050			Seam[m]	-		19.6	101.0	93.6	1.07	138.2	141.5
	0.050	1 x 0.050	0.050			1.00[m,o]	-		19.6	85.7	95.1	0.90	141.0	141.5
	0.050	1 x 0.050	0.050			1.00[m,o]	-		19.6	87.8	94.8	0.92	140.5	141.5
	0.050	1 x 0.050	0.050			1.50[m]	-		19.6	94.6	94.2	1.00	139.4	141.5
	0.050	1 x 0.050	0.050			1.50[m]	-		19.6	88.9	94.4	0.94	139.7	141.5
	0.050	1 x 0.100	0.100			1.00[m,p]	-		17.2	109.9	98.0	1.12	140.5	141.5
	0.050	1 x 0.100	0.100			2.00[m,p]	-		17.2	105.4	98.2	1.07	140.9	141.5
	0.050	1 x 0.050	0.050			Cont[n]			19.6	77.9	96.7	0.80	144.0	141.5
	0.050	1 x 0.050	0.050			Cont[n]			19.6	92.8	95.9	0.96	142.5	141.5
	0.050	1 x 0.050	0.050			4.00[n,q]	-		19.6	94.6	93.5	1.01	138.0	141.5
	0.050	1 x 0.050	0.050			4.00[n,q]	-		19.6	96.5	96.1	1.00	143.0	141.5
	0.050	1 x 0.100	0.100			Cont[n]			17.2	83.2	98.0	0.84	140.5	141.5
	0.050	1 x 0.100	0.100			Cont[n]			17.2	85.3	99.1	0.86	143.0	141.5

Table II - Continued

Specimen Cross Section	Sheet Thick. (in.)	Stiffener Size (in.)	Area of Each Stiffener (in.^{2})	No. of Stiffeners Failed	Stiffener Spacing (in.)	Rivet Pitch (in.)	Rivet Dia (in.)	Total Crack Length (in.)	Total Area Failed (pct)	$S_{net(exp)}$ (ksi)	$S_{net(cal)}$ (ksi)	$\frac{S_{net(exp)}}{S_{net(cal)}}$	$\sigma_{u(sheet)}$ (ksi)	$\sigma_{u(stiff)}$ (ksi)
	Material: PH14-8Mo(SRH 1050) $PL_{(stiff)}$ = 189 ksi										C_M = 0.70 in.$^{-\frac{1}{2}}$ W = 12 in.			
	0.025	1 x 0.010	0.010	0	4	0.30[l]	3/32	2.75	21.5	113.4	138.0	0.82	220.5	214.5
	0.025	1 x 0.025	0.025			0.50[l]	1/8		19.6	131.6	141.9	0.93	215.5	221.5
	0.025	1 x 0.050	0.050			0.50[l]	1/8		17.2	140.7	150.6	0.93	221.0	206.5
	0.025	1 x 0.010	0.010			0.30[l]	3/32		21.5	120.2	135.3	0.88	215.5	214.5
	0.025	1 x 0.025	0.025			0.50[l]	1/8		19.6	136.9	142.7	0.95	219.0	221.5
	0.025	1 x 0.050	0.050			0.50[l]	1/8		17.2	145.5	149.5	0.97	218.5	206.5
	0.025	1 x 0.010	0.010			Seam[m]	-		21.5	127.0	134.7	0.94	214.5	214.5
	0.025	1 x 0.010	0.010			Seam[m]	-		21.5	132.1	135.8	0.97	216.5	214.5
	0.025	1 x 0.010	0.010			0.20[m]	-		21.5	119.8	136.9	0.87	218.5	214.5
	0.025	1 x 0.010	0.010			0.20[m]	-		21.5	117.8	136.4	0.86	217.5	214.5
	0.025	1 x 0.025	0.025			Seam[m]	-		19.6	155.0	133.0	1.16	199.5	221.5
	0.025	1 x 0.025	0.025			Seam[m]	-		19.6	148.2	139.7	1.06	213.0	221.5
	0.025	1 x 0.025	0.025			0.50[m,o]	-		19.6	168.2	143.0	1.17	219.5	221.5
	0.025	1 x 0.025	0.025			0.50[m,o]	-		19.6	161.8	144.0	1.12	221.5	221.5
	0.025	1 x 0.025	0.025			0.75[m]	-		19.6	114.5	140.7	0.81	215.0	221.5
	0.025	1 x 0.025	0.025			0.75[m]	-		19.6	112.4	140.5	0.79	214.5	221.5
	0.025	1 x 0.050	0.050			1.00[m,p]	-		17.2	140.1	148.2	0.94	215.5	206.5
	0.025	1 x 0.050	0.050			1.00[m,p]	-		17.2	141.3	145.7	0.96	209.5	206.5
	0.025	1 x 0.025	0.025			Cont[n]	-		19.6	152.2	140.7	1.08	215.0	221.5
	0.025	1 x 0.025	0.025			Cont[n]	-		19.6	165.7	142.5	1.16	218.5	221.5
	0.025	1 x 0.025	0.025			2.00[n,q]	-		19.6	125.9	135.8	0.92	205.0	221.5
	0.025	1 x 0.025	0.025			2.00[n,q]	-		19.6	120.8	134.3	0.90	202.0	221.5
	0.025	1 x 0.050	0.050			Cont[n]			17.2	160.0	150.6	1.06	221.0	206.5
	0.025	1 x 0.050	0.050			Cont[n]			17.2	178.7	150.8	1.18	221.5	206.5

Table II - Concluded

a. Outboard stiffener area = 0.480 in.^{2} (each)

b. Outboard stiffener area = 0.339 in.^{2} (each)

c. Outboard stiffener area = 0.246 in.^{2} (each)

d. Outboard stiffener area = 0.171 in.^{2} (each)

e. Spacing from ℄ as follows: 2.5, 9, 15 in.

f. Stiffener bonded in grips only

g. Stiffener bonded full length

h. Notch radius = 0.005 in.

i. Area each strap = 0.037 in.^{2}

j. Area each strap = 0.084 in.^{2}

k. Strap and stiffener failed

l. Mechanical fasteners (Monel rivets)

m. Spot-weld

n. Fusion weld

o. Longidtudinal butt-weld in skin at straps

p. Two rows staggered

q. Intermittent weld; 2.0-in. weld, 2.0-in. gap

The predictions obtained by using Equation 1 for all the available data are presented in Table II and in Figure 4 as tick marks. The experimental data are shown as symbols in the figures. The symbol F above the stiffeners indicates that the stiffener had been failed prior to testing. These data include specimen widths ranging from 12 inches to 57 inches, specimens with either riveted or welded stiffeners, and specimens containing either notches or fatigue cracks. It can be seen from Figure 4 that, in general, the predictions for the 7075-T6 aluminum panels discussed previously are higher than those for the 2024-T3 aluminum panels and thus tend to conform with the observed trends in Figures 1 and 2. The average differences between the calculated values and the experimental data for each material are presented in Table III.

TABLE III. AVERAGE DIFFERENCES BETWEEN CALCULATED AND EXPERIMENTAL DATA

Material	No. of Points	$\frac{\Sigma \lvert S_{net(cal)} - S_{net(exp)} \rvert}{\text{No. of Points}}$
2024 - Bare and Clad	43	2.8 ksi
7075 - Bare and Clad	26	6.0 ksi
Ti8Al-1Mo-1V		
Riveted	6	5.0 ksi
Welded	18	8.3 ksi
PH14-8Mo (SRH 1050)		
Riveted	6	11.6 ksi
Welded	18	15.7 ksi

The average differences for the Ti8Al-1Mo-1V panels with welded stiffeners and for the PH14-8 panels with either riveted or welded stiffeners are somewhat large. However, investigation indicates that there were differences of as much as 14.9 and 18.7 ksi for the Ti8Al-1Mo-1V and PH14-8 panels, respectively, in the results of tests on similar specimens. Based on this observation, the large differences between the calculated and experimental values for these cases are not considered to be unreasonable.

Even though typical values of the material constant, C_M, and the proportional limit were used for each material, with no attempt to adjust the values for each set of data, and even though there was inherent scatter in residual strength data on stiffened panels, the predictions are considered to be quite good. As can be seen in Figure 4, the method produced acceptable results for a wide range of configurations, type fasteners, and crack geometry.

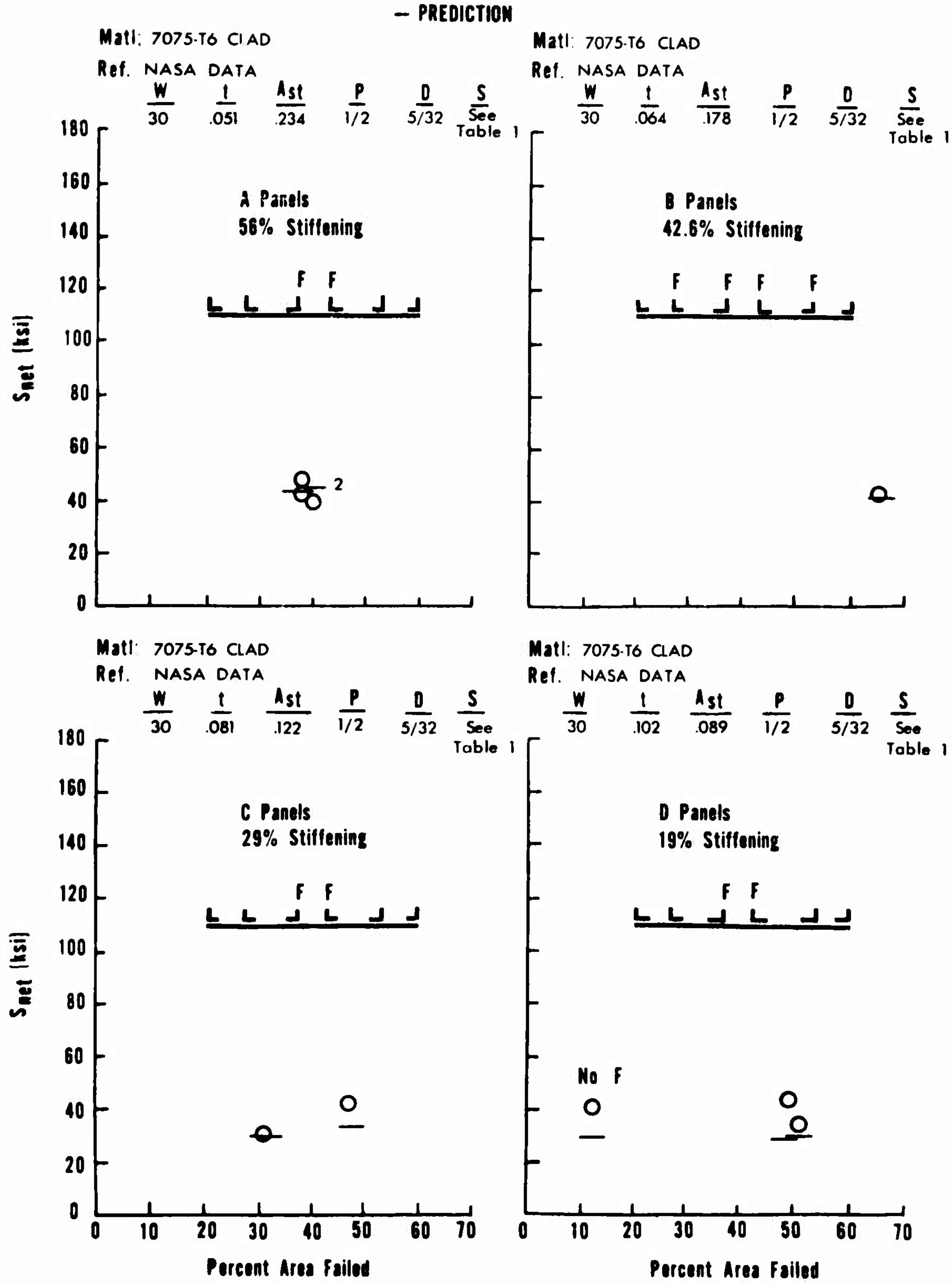


Figure 4. Experimental and Predicted Strengths of Stiffened Panels.

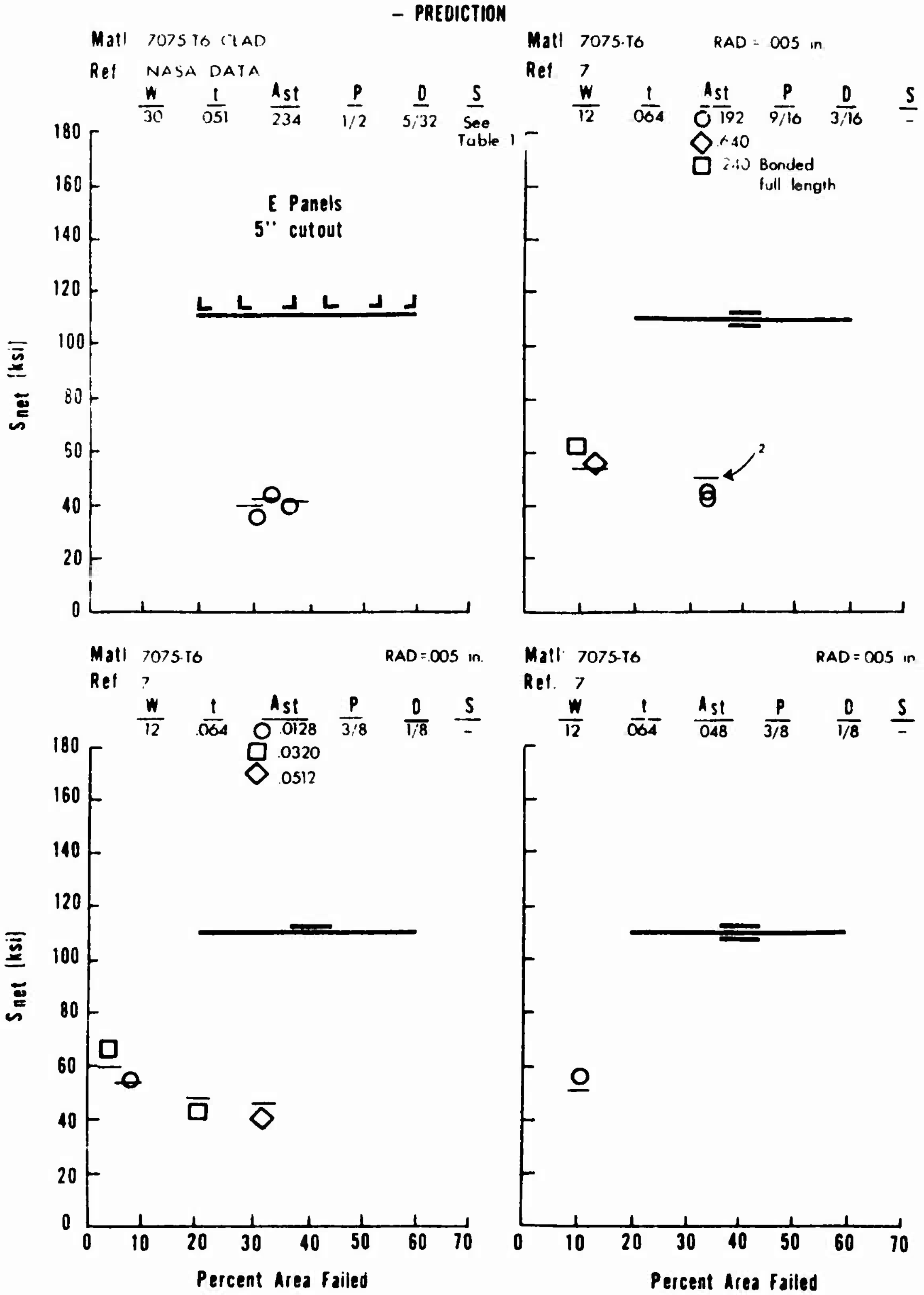


Figure 4. Continued.

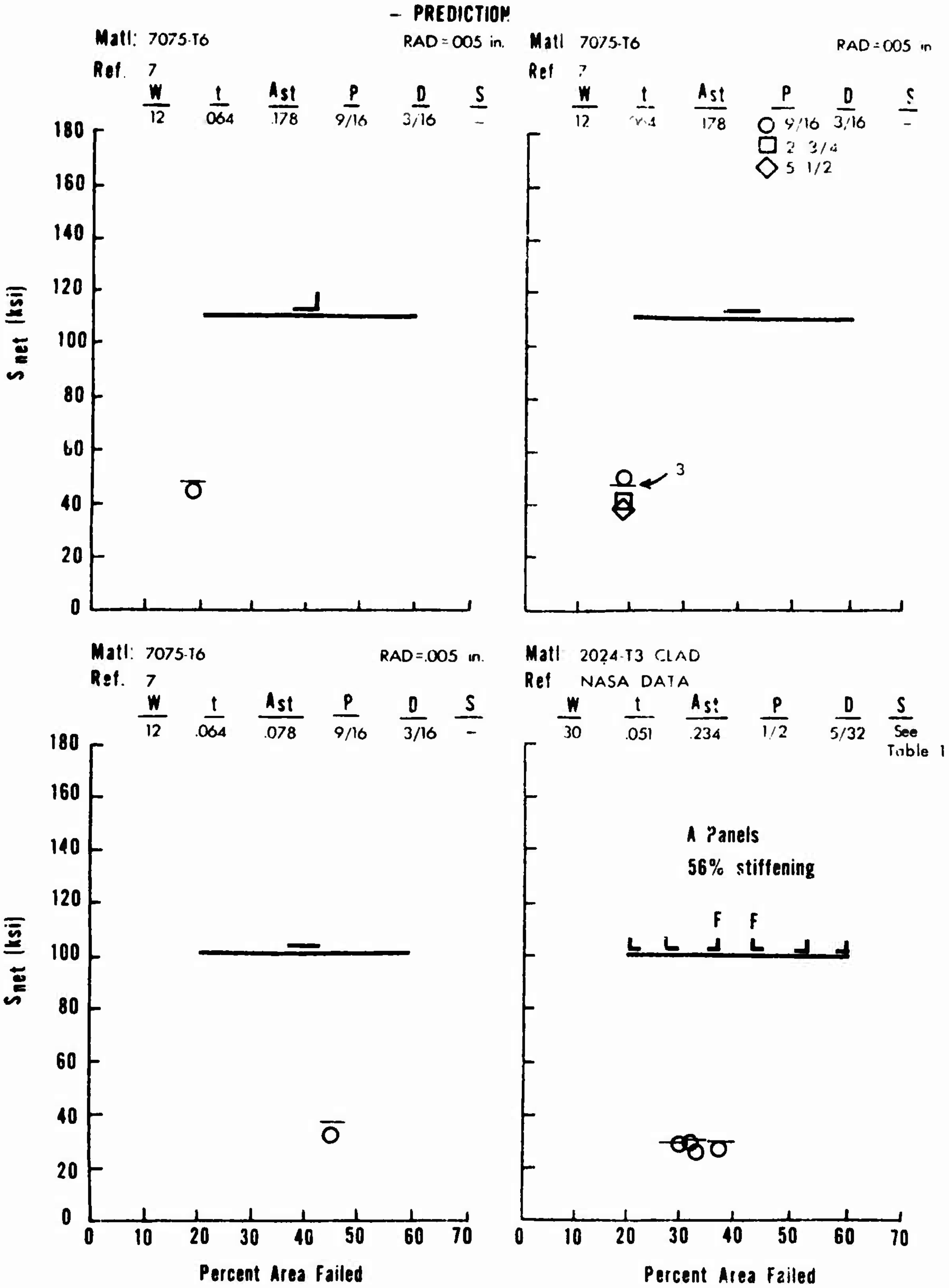


Figure 4. Continued.

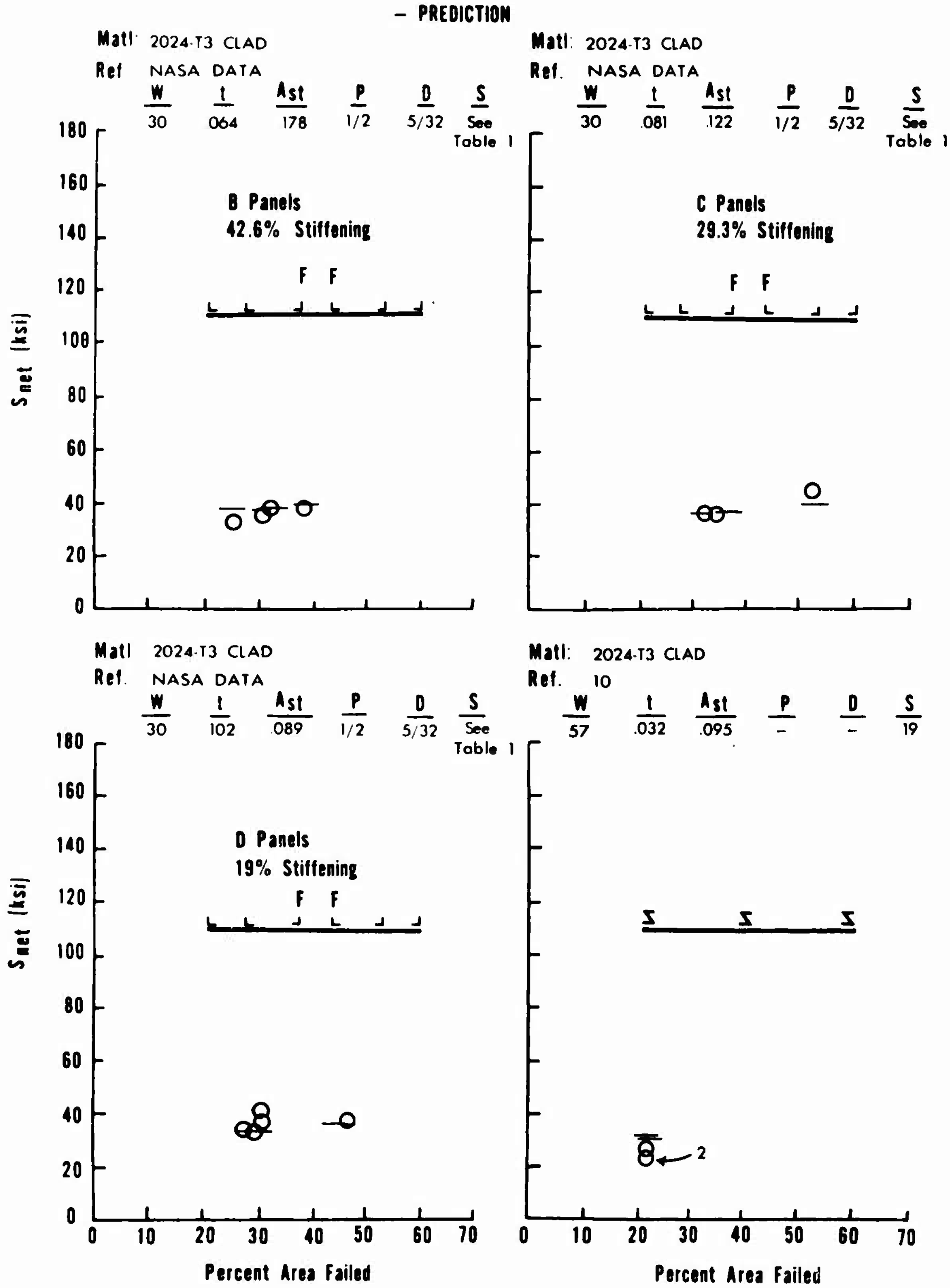


Figure 4. Continued.

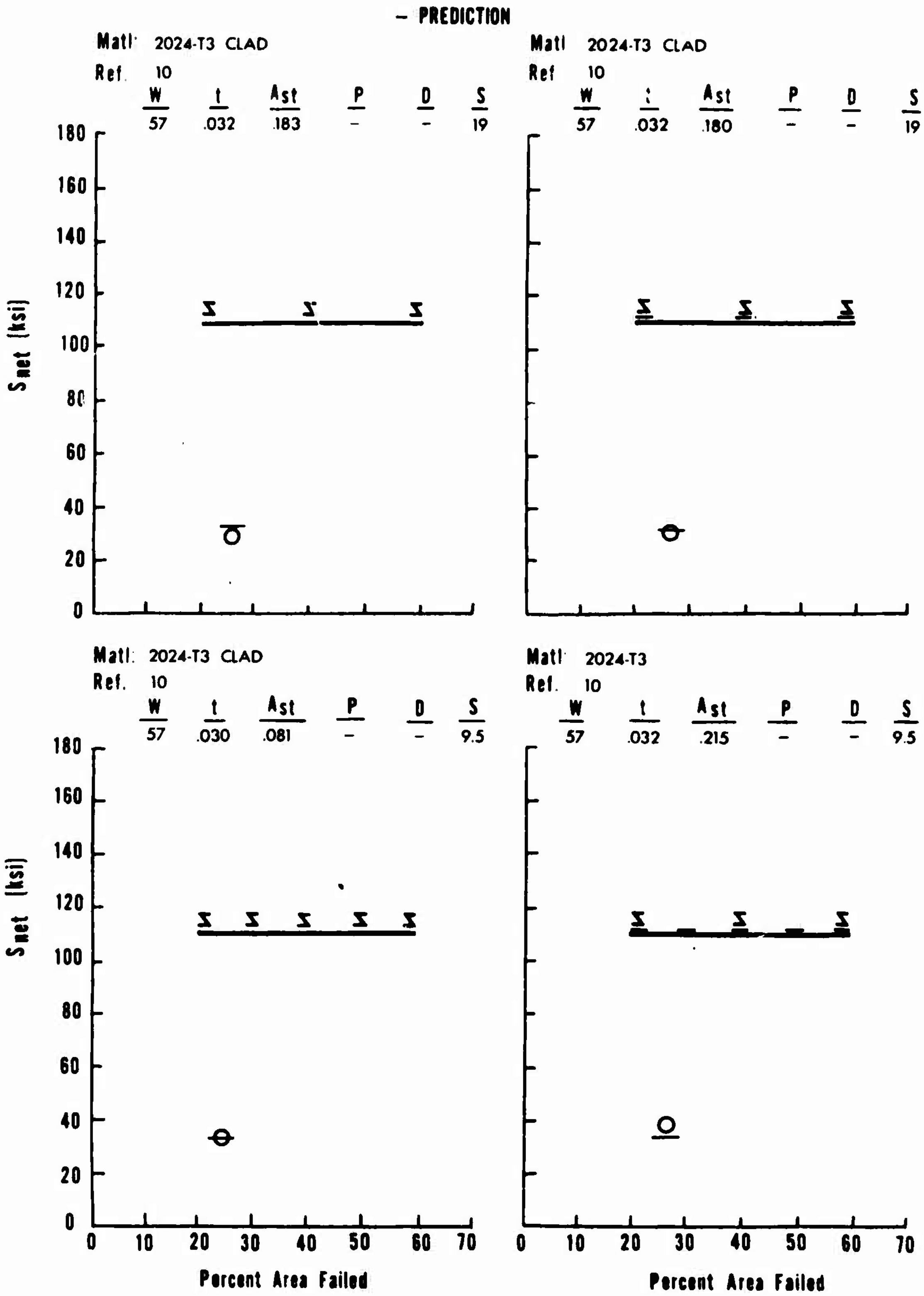


Figure 4. Continued.

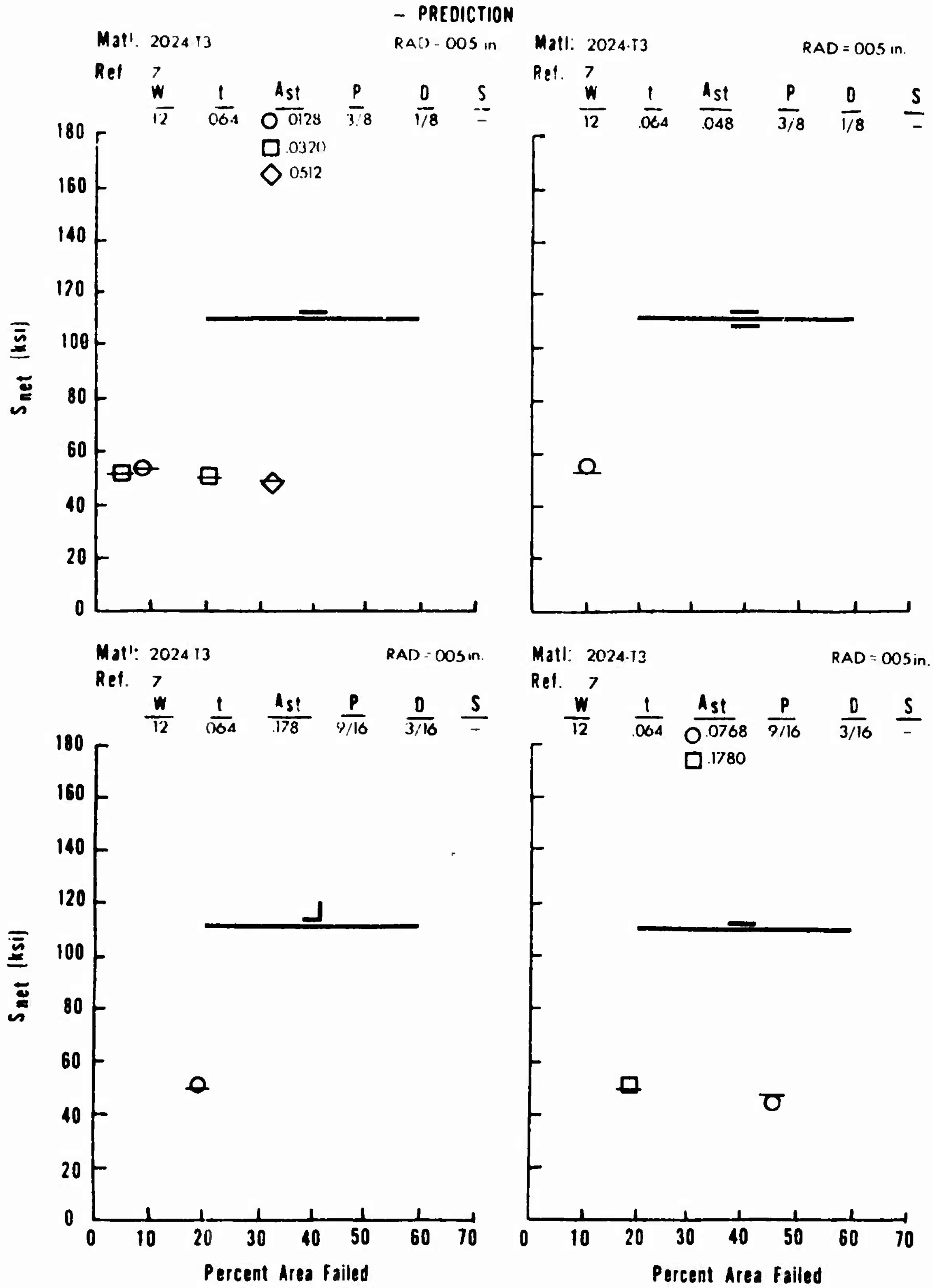


Figure 4. Continued.

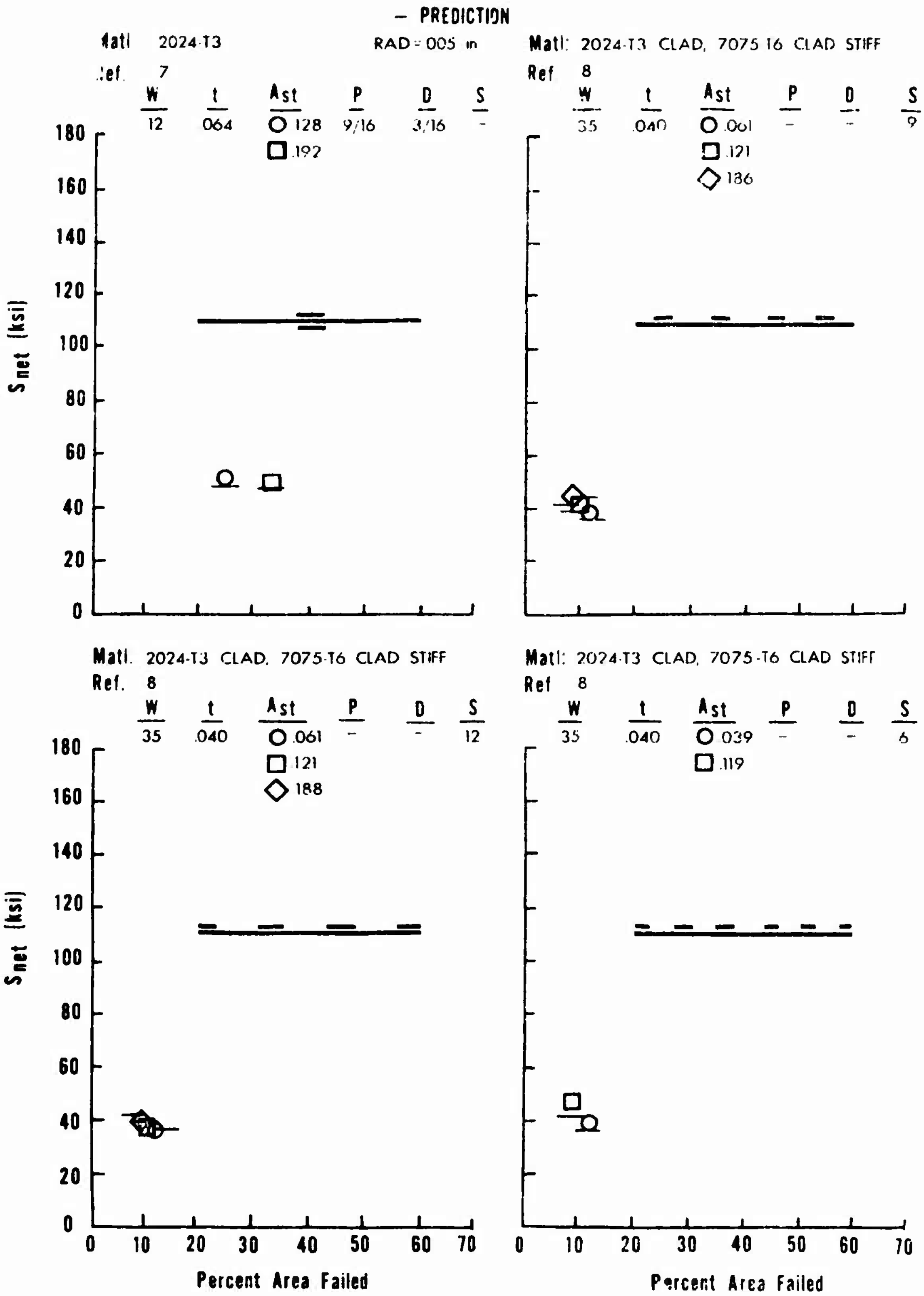


Figure 4. Continued.

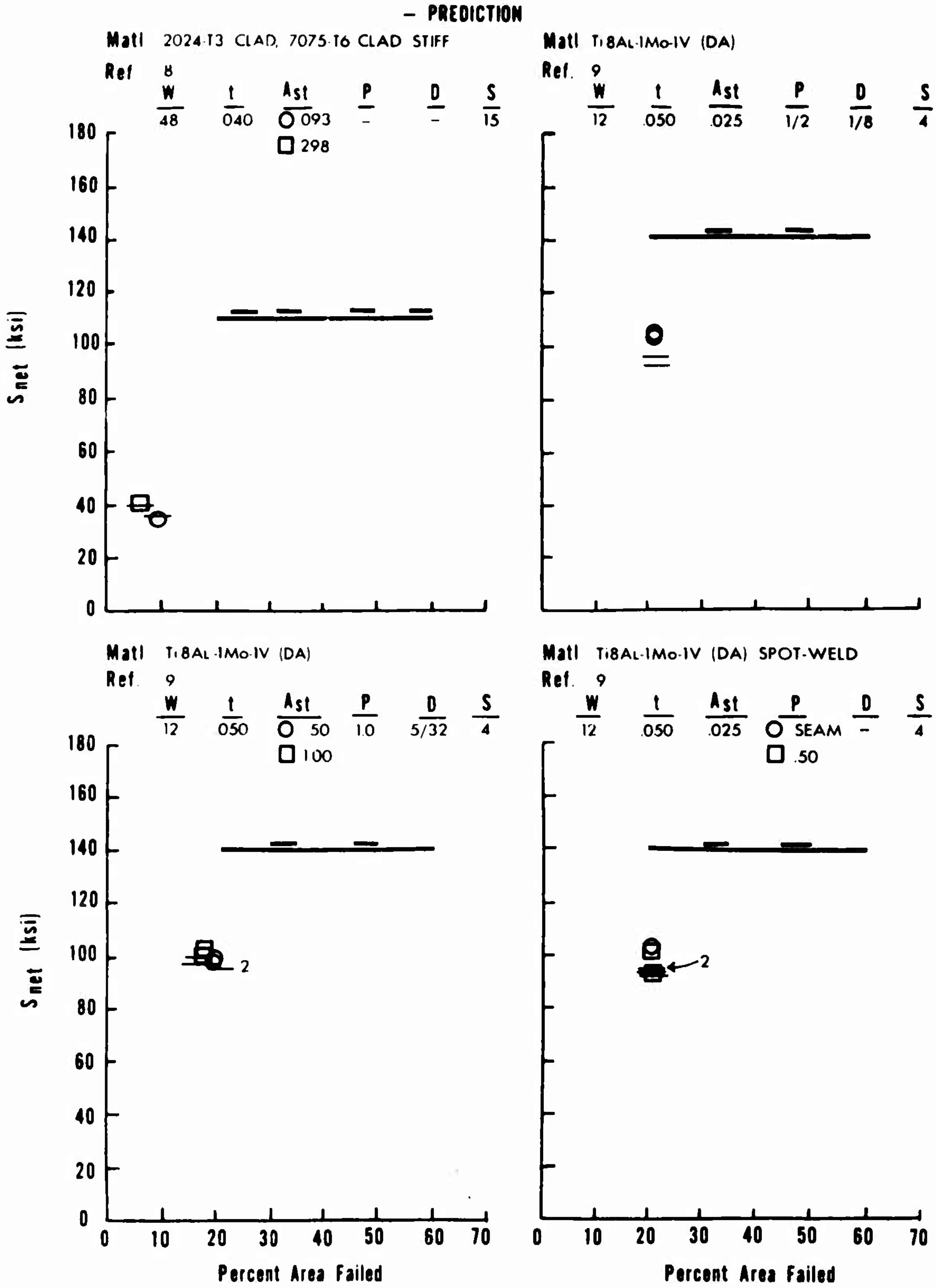


Figure 4. Continued.

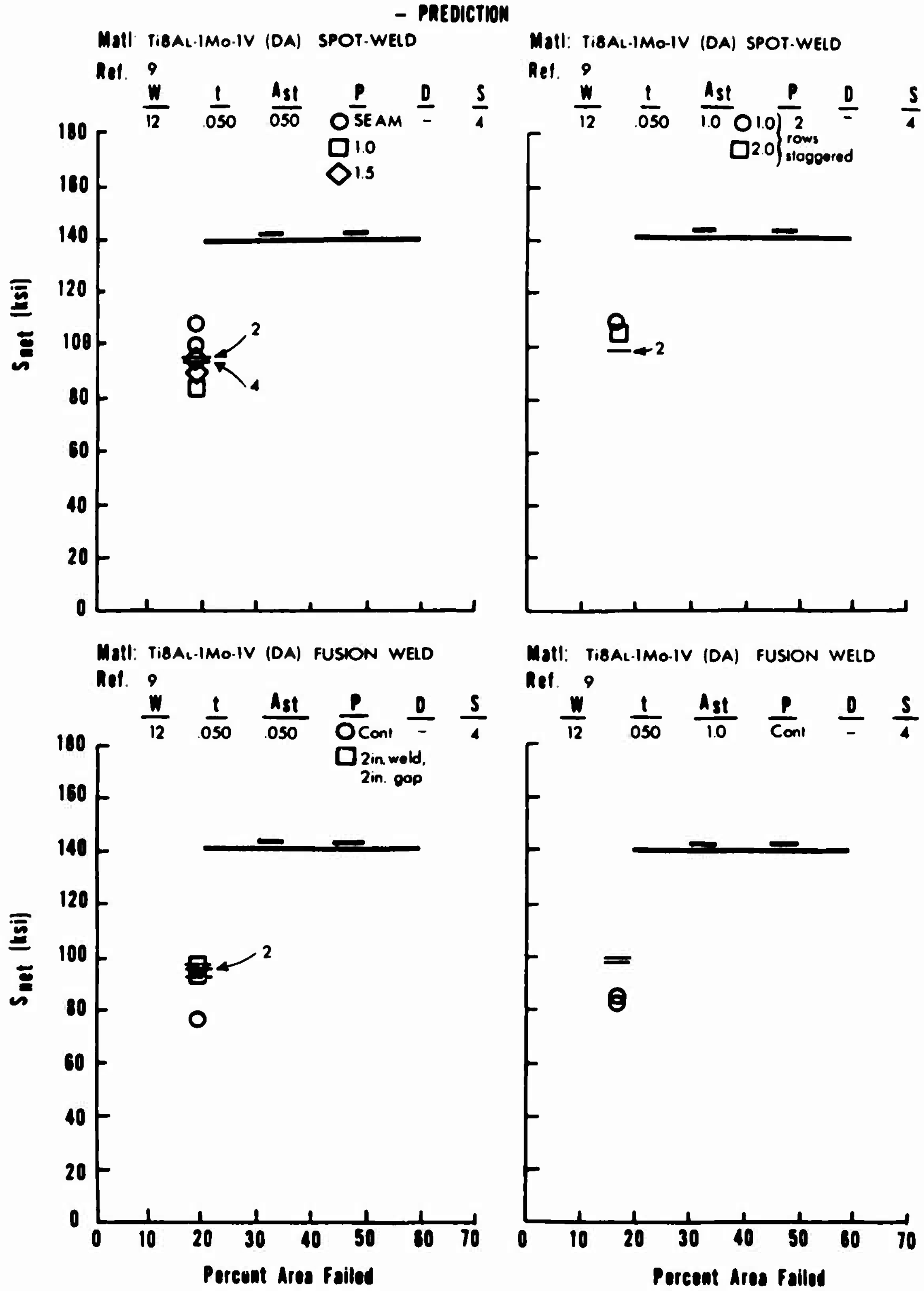


Figure 4. Continued.

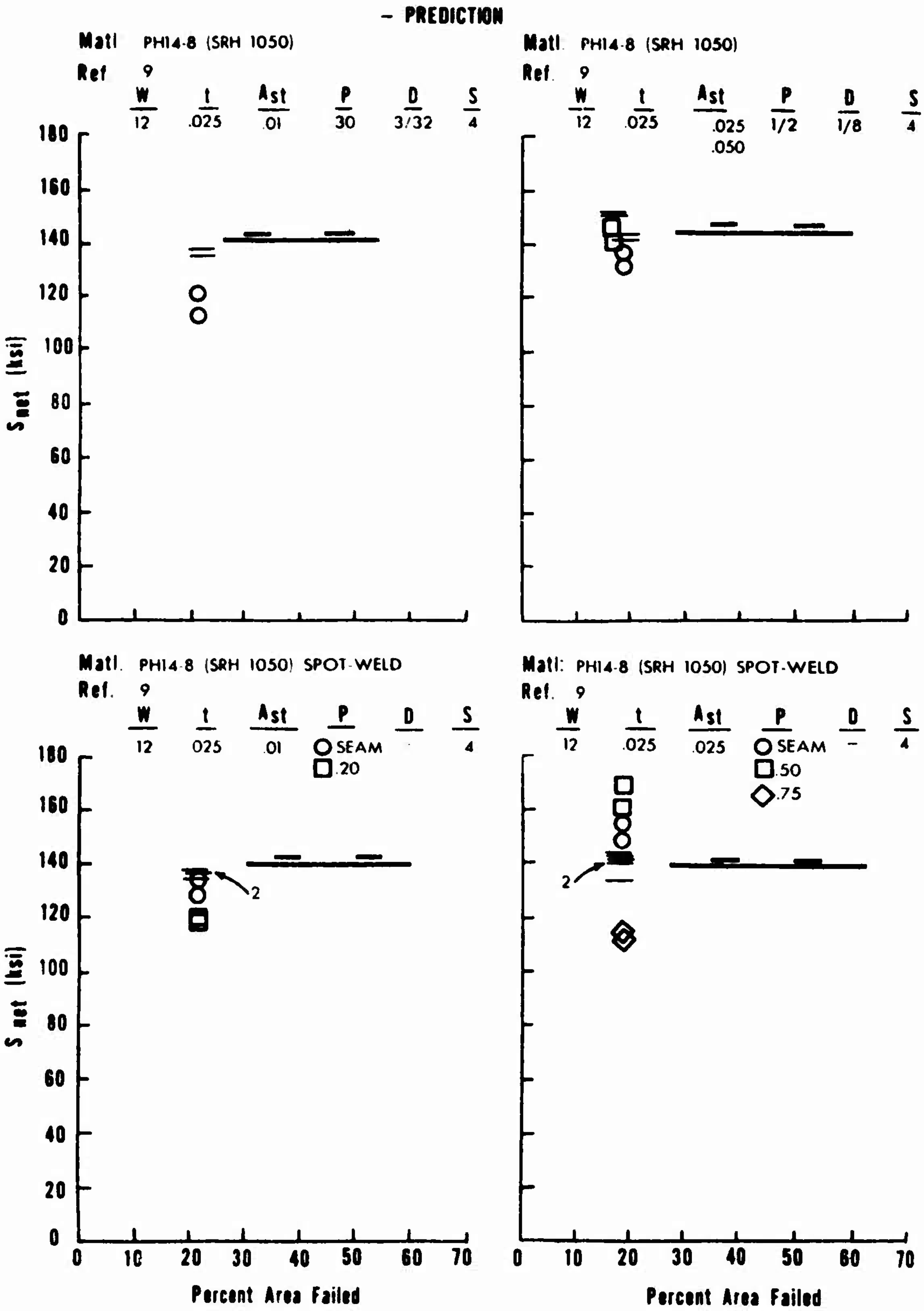


Figure 4. Continued.

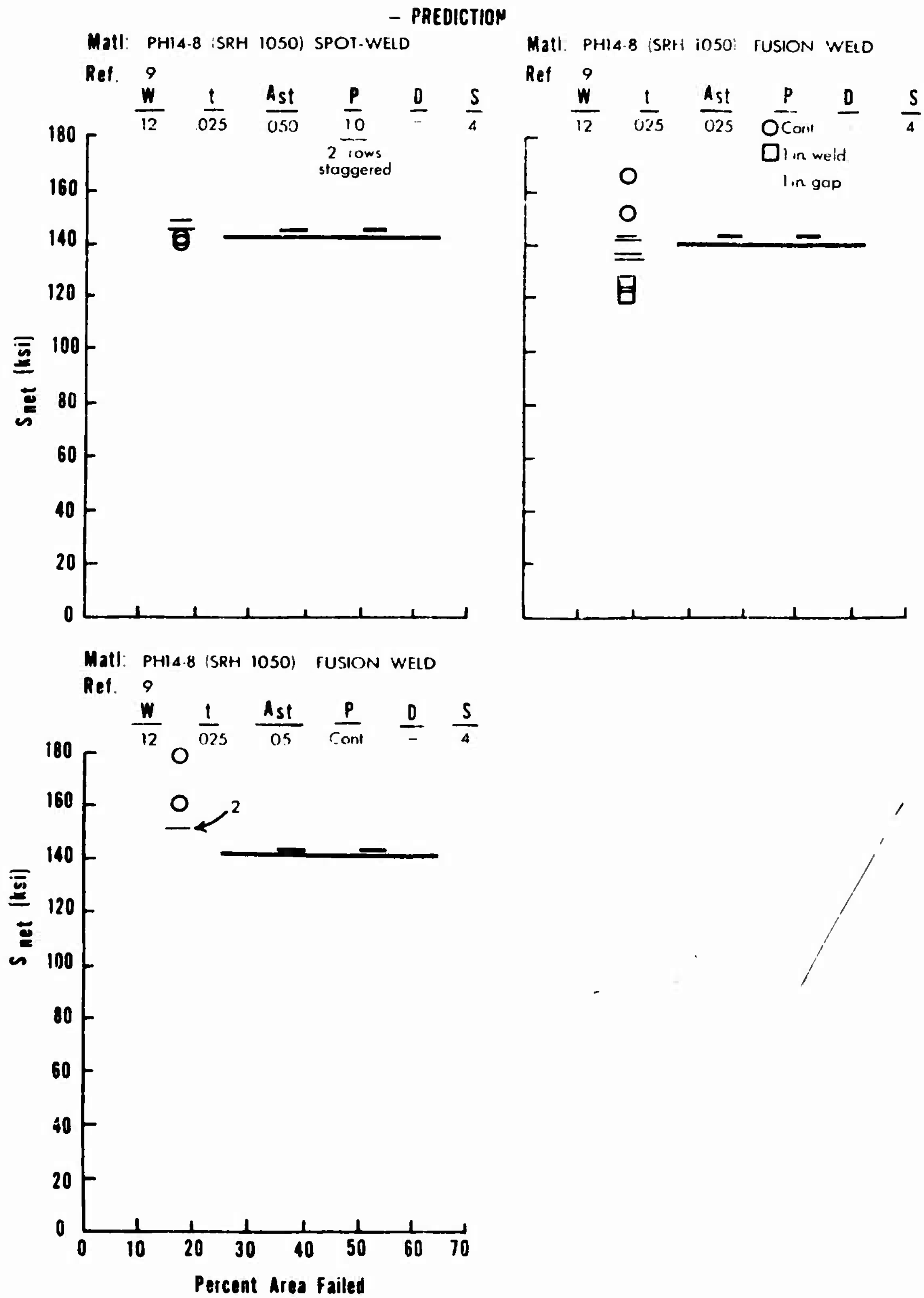


Figure 4. Concluded.

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13. ABSTRACT

An equation has been developed to predict the residual static strength of stiffened panels. All parameters in the equation can be evaluated from tests on simple unstiffened specimens. The stiffened panel is treated as a composite material, with the sheet material representing the matrix and the stiffeners representing the fibers. The residual static strength of the cracked sheet, calculated using notch strength analysis, and the proportional limit of the stiffeners are used in the law-of-mixtures equation to calculate the residual static strength of the stiffened panels.

Excellent predictions of the residual static strength of stiffened panels have been obtained and are presented for a wide variety of panel configurations, type fasteners, and crack geometry.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Stiffened Panels						
Fracture Toughness						

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